Final Technical Report for NASA NAG 5-1260
Prepared by Dr. Lynn R. Cominsky, Principal Investigator
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This report covers the period September 1, 1989 through September 1, 1995 for NASA grant NAG 5-1260 through the Astrophysics Data Program (ADP), for the project **"High Time Resolution Studies of Binary X-ray Pulsars"**, Dr. Lynn R. Cominsky, Principal Investigator, Department of Physics and Astronomy, Sonoma State University, Rohnert Park, CA 94928.

The work for this project was substantially more than anticipated, and involved recreating an analysis system for all the HEAO A-1 scanning data which had been converted to the ELE format. As a result of this work, a complete software analysis package was first created at Sonoma State University using Fortran, that can extract the data for any given X-ray source, and produce light curves from the scanning data. This involved converting many old routines to run in the Unix environment, as well as creating many new routines to do timing corrections for such things as the solar system barycenter. A second complete software analysis package was also created, this time in IDL, which can also display all the data in a timely manner, allowing data screening without the generation of hardcopy plots. Both these software systems are now in residence at SSU and at the Stanford Linear Accelerator Center, and are available for public use upon request. They will be an asset for comparing results from the newly launched Rossi X-ray Timing Explorer to archival data.

However, the creation of the software systems was not the original goal of the project; rather this was a necessary result when the NRL computers became inoperable due to old age and could not be used to support the project, as originally planned. There were 6 sources originally proposed for analysis:
SMC X-1, A0538-66, LMC X-1, LMC X-3, (these 3 sources are all located in the Large Magellanic Cloud region), 4U0115+63 and 4U1626-67. Below are listed the (mostly null) results on these sources.

1) SMC X-1. We searched most of the existing 5 ms data for this 0.71 s pulsar, but the source is turned off during most of these observations. Pulsations are only marginally detected in the 320 ms data, due to the closeness to the Nyquist limit. As timing accuracy is required in order to improve on the orbital period determination using the Doppler shift technique, it does not seems likely that this scientific objective will be able to be accomplished. We have, however produced a scanning light curve for this source from the existing data.

2, 3 and 4) LMC region. We detected several previously unreported outbursts from the 17 day cycle of A0538-66 (which is almost always confused with LMC X-4), and searched the data for evidence of the reported 69 ms pulse period. We were not able to confirm this period. As PSR0540-69 is also in this data set (and almost always confused with the much stronger but non-pulsing LMC X-1) we also looked for 50 ms

pulses from this object, but could not find any. Light curves for the two black hole candidates LMC X-1 and LMC X-3 did not yield any obvious orbital information or pulsations.

5) 4U0115+63. We analyzed the scanning data and produced light curves from 4U0115+63, but the data were insufficient to improve the orbital period determination, as originally hoped.

6) 4U1626-67. We analyzed the scanning data and produced light curves from 4U1626-67, but the data were insufficient to improve the orbital period determination, as originally hoped.

In addition, using our new analysis system, we also analyzed the following sources which were not originally listed in the proposal with the (more interesting) results summarized below.

a) Her X-1. Although no new results were obtained, we succeeded in obtaining light curves which clearly show the well known eclipses and pre-eclipse dips for several orbital cycles. We used this source as a test to debug our software for performing FFTs of both 320 and 5 ms data.
b) Am Her. We determined the orbital period using periodogram analysis as a test of the new software on a fairly faint source.
c) New transients. Several new transient sources were reported in the IAU circulars,and we have checked for any prior outbursts in the A-1 data base. No prior outbursts were seen from either J0422+32 or GRS2037-404.
d) Gamma Cas. This Be binary was searched for pulsations, but none were found.
e) GX339-4 is a highly variable black hole candidate for which we reported a previously unknown outburst in the archival HEAO data. We have attempted to determine the role of this outburst with respect to the recently reported long term period by the BATSE team, but it does not seem to fit the pattern. Long term periods in black hole systems are associated with precessing accretion disks around the central object, and are relatively rare.
f) We also found a previously unstudied outburst from the black hole candidate 4U1630-47. This source had indications of a 600 day outburst cycle, which was not confirmed with our new data. The source remains in an on state for many months after the outburst occurs, thus conflicting with the periodic behavior formerly seen.
g) For the black hole candidate X1755-33, we have seen evidence of the absorption dips caused by the accretion disk around the central black hole candidate object. In all previous data these dips were only partial, but we reported evidence for one dip which is total - to a very low luminosity limit, as determined by the sensitivity of the A-1 detectors. These results on the black hole candidates are being prepared for submission to a refereed journal as part of an archival study of all the black hole candidates in the A-1 data base and will appear in a forthcoming PhD thesis from Stanford graduate student Han Wen.

h) The neutron star source 4U1907+09 is interesting as it has two absorption dips in every orbit. These dips cannot be easily explained by conventional models unless the orbit of the neutron star is inclined with respect to the axis of a disk of matter - either an accretion disk around the neutron star or an extended disk of emission around the companion star. We have confirmed that these dip features (which were originally reported in EXOSAT and TENMA data from the early 1980s) are stable going back to our data from 1978. We also see evidence for the pulsation period reported by these authors.

Work on the black hole publication is still in progress, supported by the Stanford Linear Accelerator Center and this grant will be acknowledged when it is finally published. Work on 4U1907+09 continues with new observations from ASCA. The HEAO data will be combined with these new observations in a publication in the future.

Publication list: HEAO A-1 Archival Observations of Galactic X-ray Binaries, Cominsky, L. R., Roberts, M., Lee, A. and Segel, D. BAAS, 26, 872 (1994).